Energy Resources

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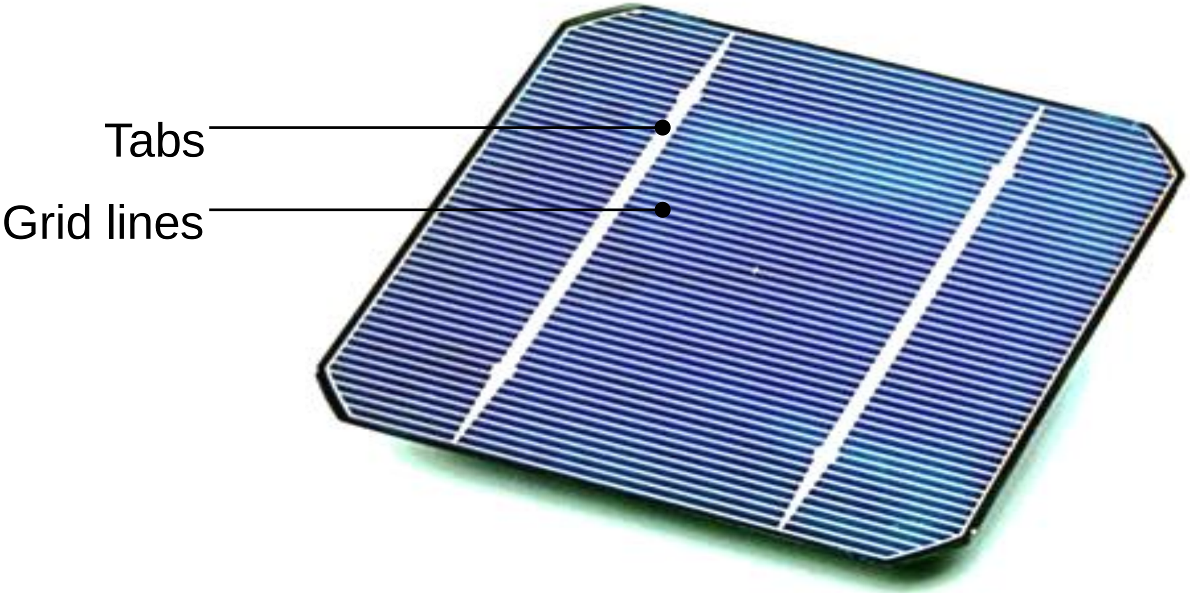
Solar Energy

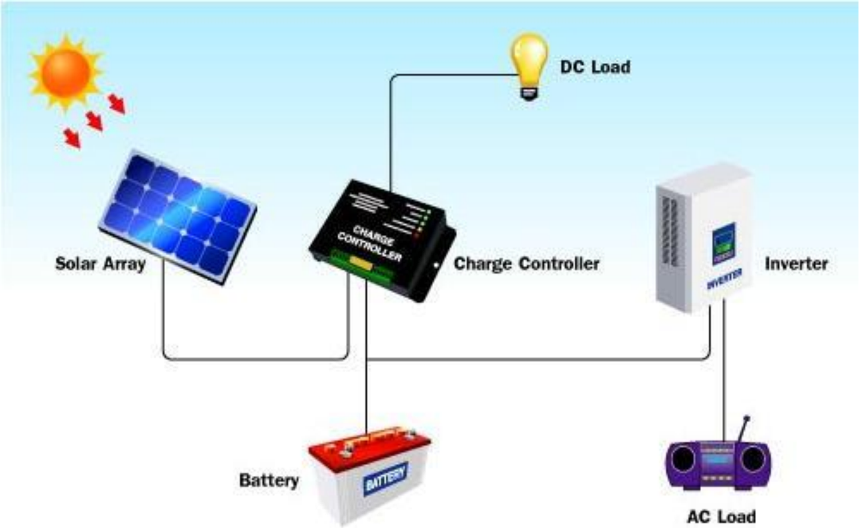
The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9 m and is, on the average, 1.5×10^{11} m from the earth.

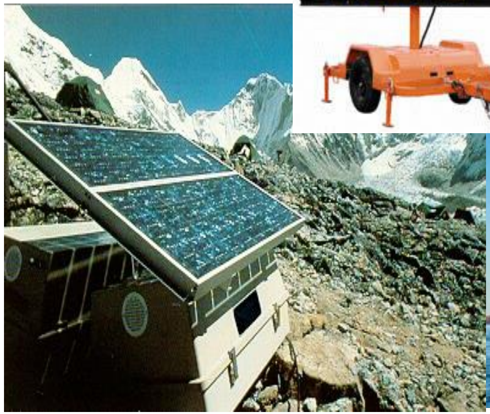
The sun has an effective blackbody temperature of 5777 K.

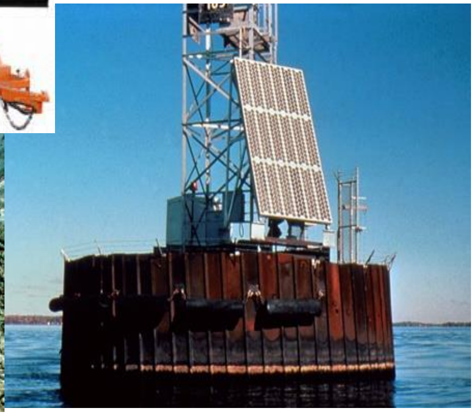
Electricity from solar energy



Electricity from solar energy







Quaid-e-Azam Solar Park

“The plant is giving an average yield of 169 gigawatt hour against the annual target of 153GW hour to meet 153 million units production requirement,”

https://www.qasolar.com/

Quid e Azam Solar Park

- Average daily irradiation amounts to **5-7 kWh/m^2** with 3000 hours of sunshine available annually.

- Government of Punjab has allocated **6,500 acres (26 km^2)** of land in Southern Punjab for “Quaid-e-Azam Solar Park”

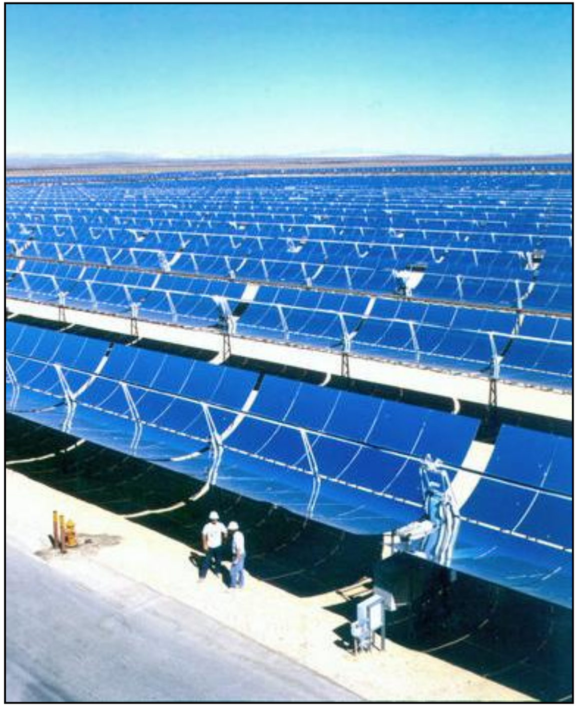
- The solar park has a total potential of more than 1,000 MW. The Government of Punjab is launching its flagship project of 100 MW Solar PV Power to set the ball rolling.

- Solar power projects are exempted from custom duty, sales tax, income tax, turnover tax and withholding tax on imports

Solar water heating

Evacuated tube collector on a roof in Germany

Solar thermal system for power generation

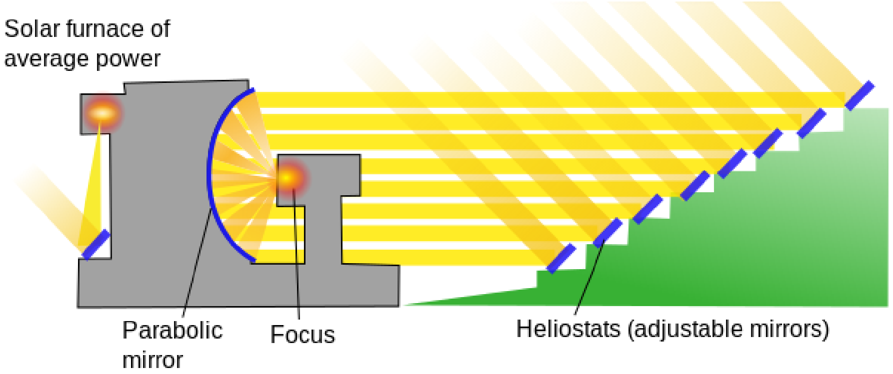


Power tower at CESA in Spain

Solar furnace in France

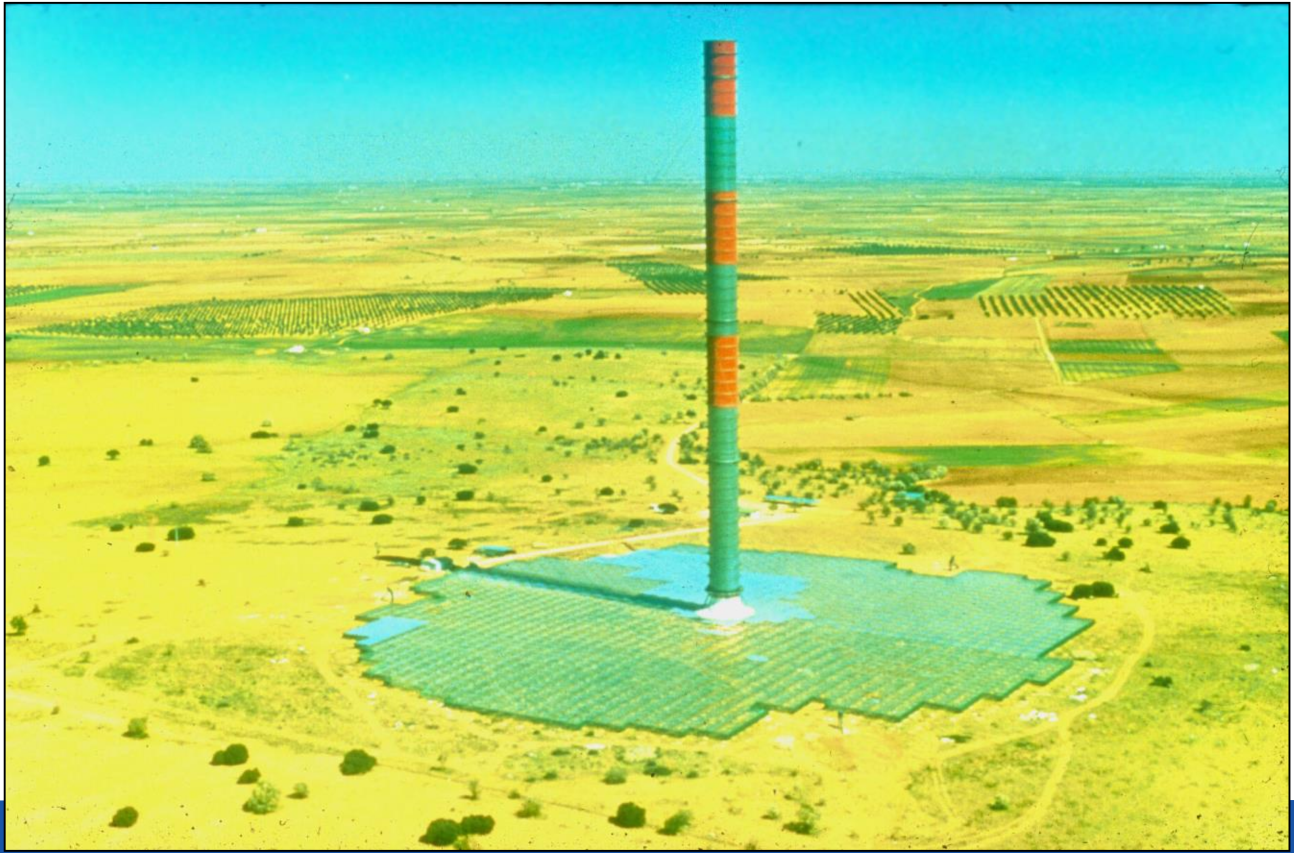
Solar furnace in France

- Incident solar radiation is converged towards a circular target on top of a central tower; this target was only 40 cm in diameter. That is equivalent to concentrate the energy of "**10,000 suns**.“
- Temperatures above 3,500 °C (6,330 °F) can be obtained in a few seconds.
- The energy is "free", and non-polluting.
- This furnace provides rapid temperature changes and therefore allow studying the effect of thermal shocks;

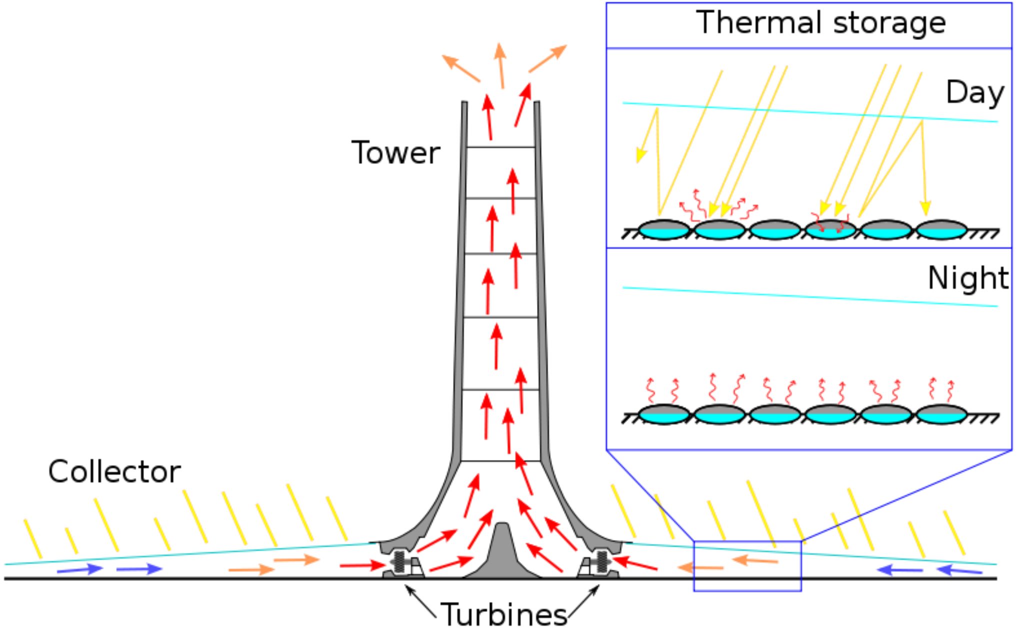


Solar furnace generating 1 megawatt

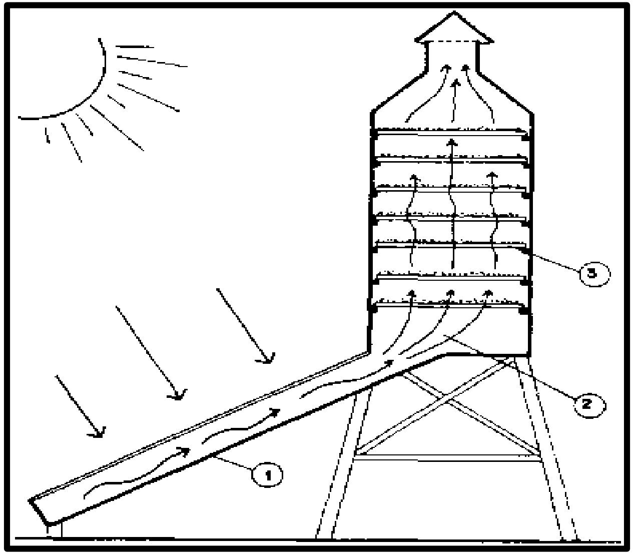
Solar Chimney in Spain



Solar Chimney in Spain



Drying agricultural products



Solar roof in the USA

Solar challenge

Energy consumption in Pakistan

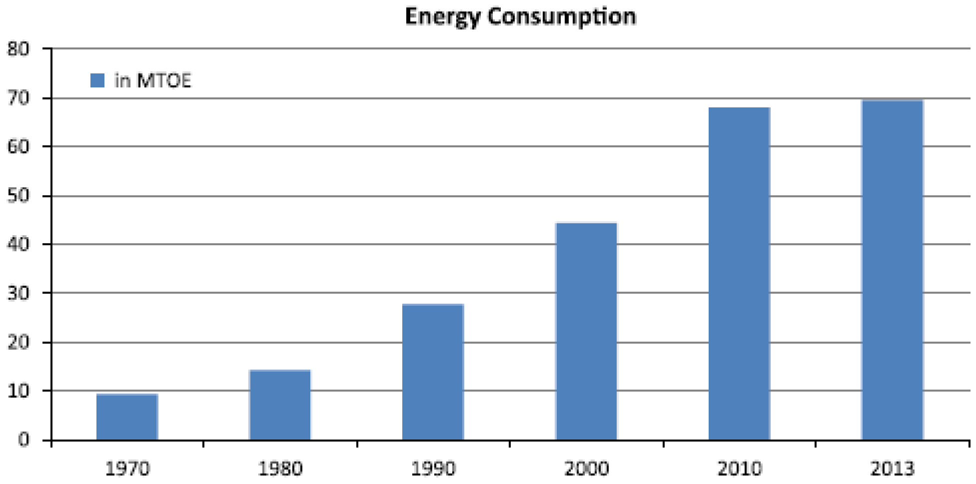


Fig. 2. Pakistan energy consumption from 1970 to 2013.

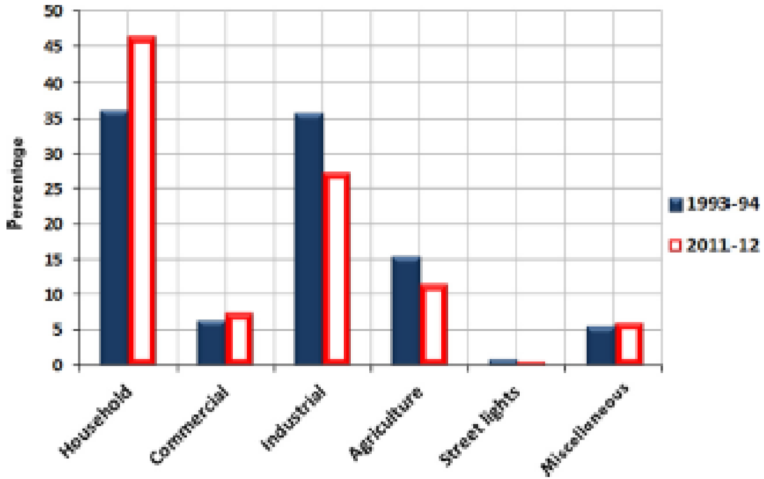


Fig. 2. Sector wise percentage consumption of electricity in Pakistan [16].

Energy consumption-Pakistan vs Rest of world

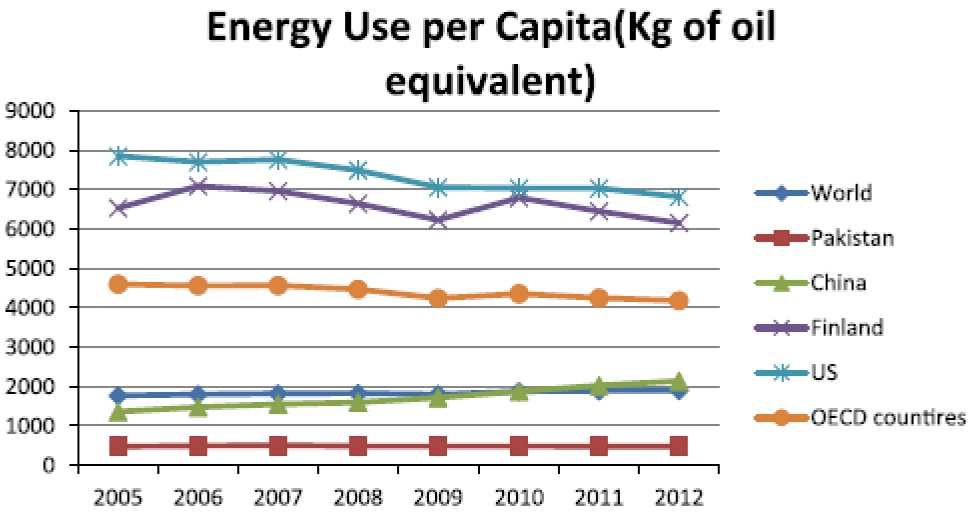


Fig. 1. Comparison of per capita energy consumption.

Energy demand and primary energy sources

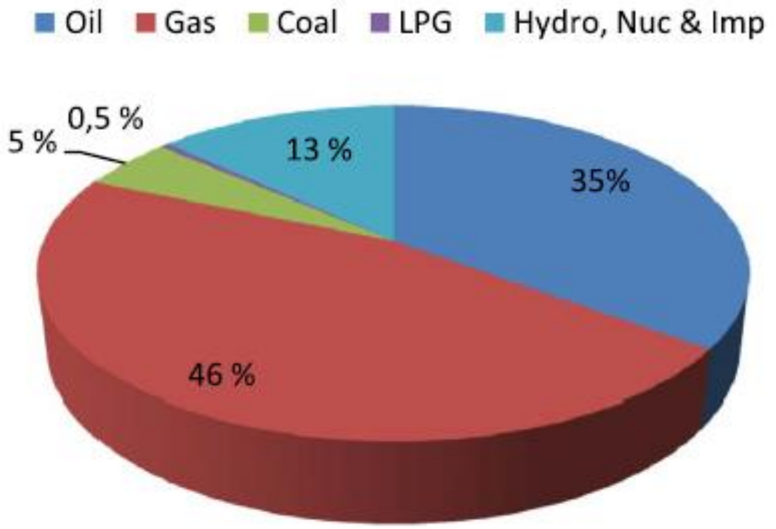


Fig. 5. Total primary energy supplies by source in 2014.

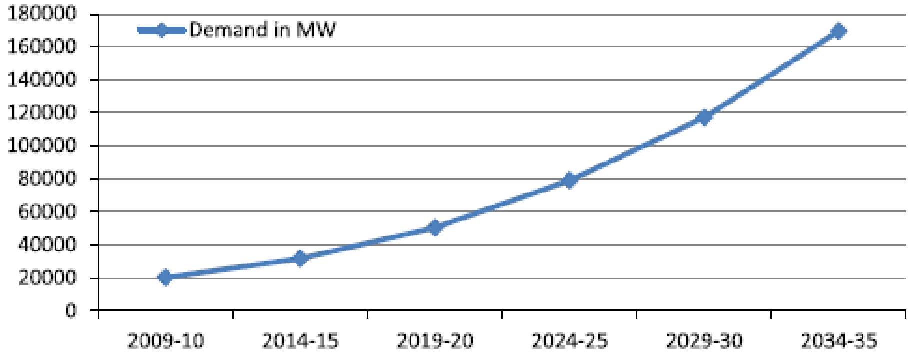


Fig. 4. Electricity demand forecasts from 2011 to 2035.

Carbon emissions and cost of electricity

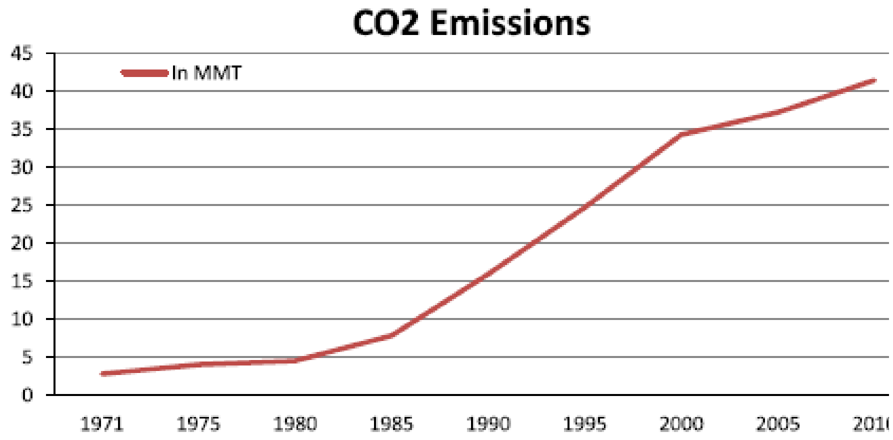


Fig. 9. Electricity related CO_2 emissions in Pakistan.

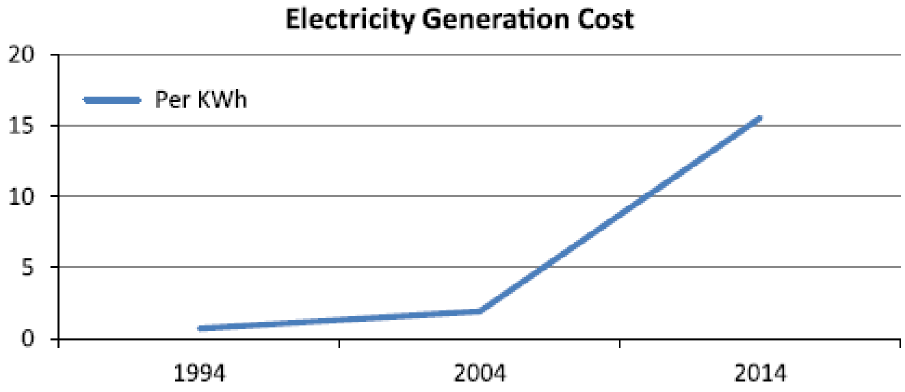


Fig. 10. Electricity generation cost per kW h in Rs.

Carbon emissions and cost of electricity

According to Kafaitullah,the energy sector contributes over 80% of all the CO_2 emissions in Pakistan. In 2010,Pakistan produced 164 million metric tons (MMT) of carbon emissions, out of which 42 MMT came from electricity, approximately 25% of all the emissions.

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Solar Energy Potential

Availability - Higher in warm and sunny countries, (where most of the growth – population, economy, and energy demand – will take place in this century)

These countries will have approx. 7 billion inhabitants by 2050, *versus* 2 billion in cold and temperate countries (including most of Europe, Russia and parts of China and the United States).

Source : IPCC, 2009

Solar Energy Potential

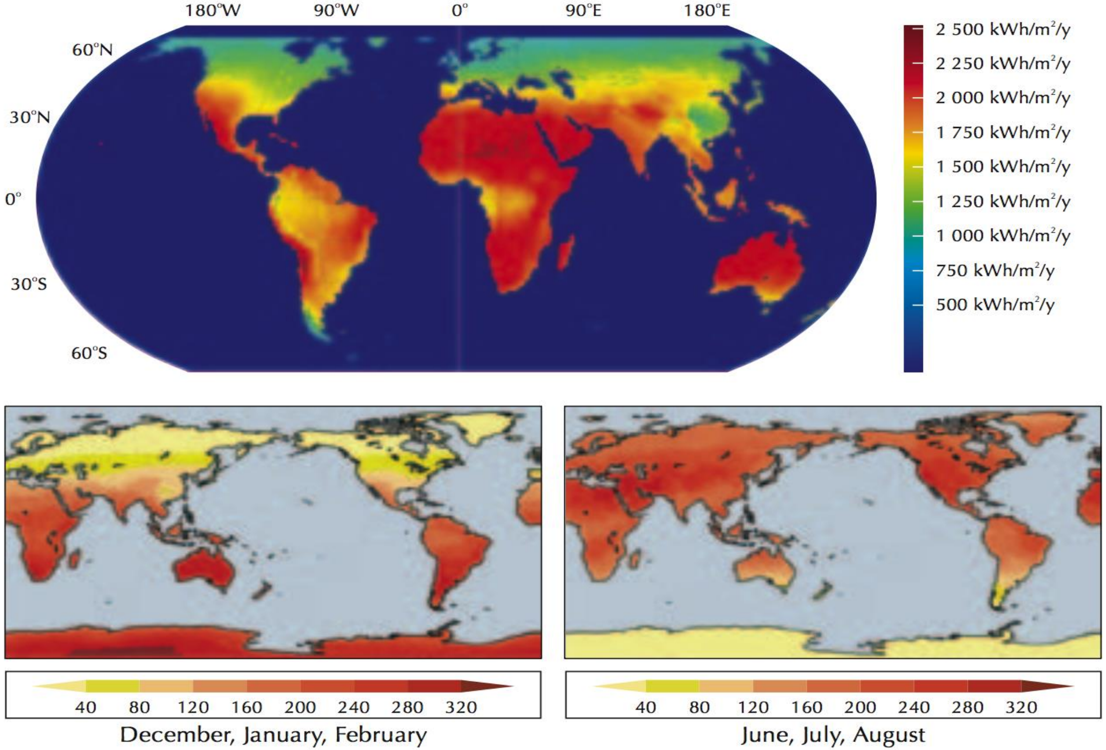
Currently sun takes 1hr & 25 minutes to send us the amount of energy we currently consume in a year, and approx. 4.5hrs to send the same amount of energy only on land.

By 2035, > 2hrs for overall planet and less than 7hrs on land.

A comparison focused on final energy demand would significantly reduce these numbers – to 1hr of sunshine on the whole planet or 3.25 hrs on land today, and by 2035 1.5hr or 4.75 hrs.

Source: IEA, 2011

Solar Energy Potential



Sources: (top) Breyer and Schmidt, 2010a; (bottom) ISCCP Data Products, 2006/IPCC, 2011.

Solar Radiation

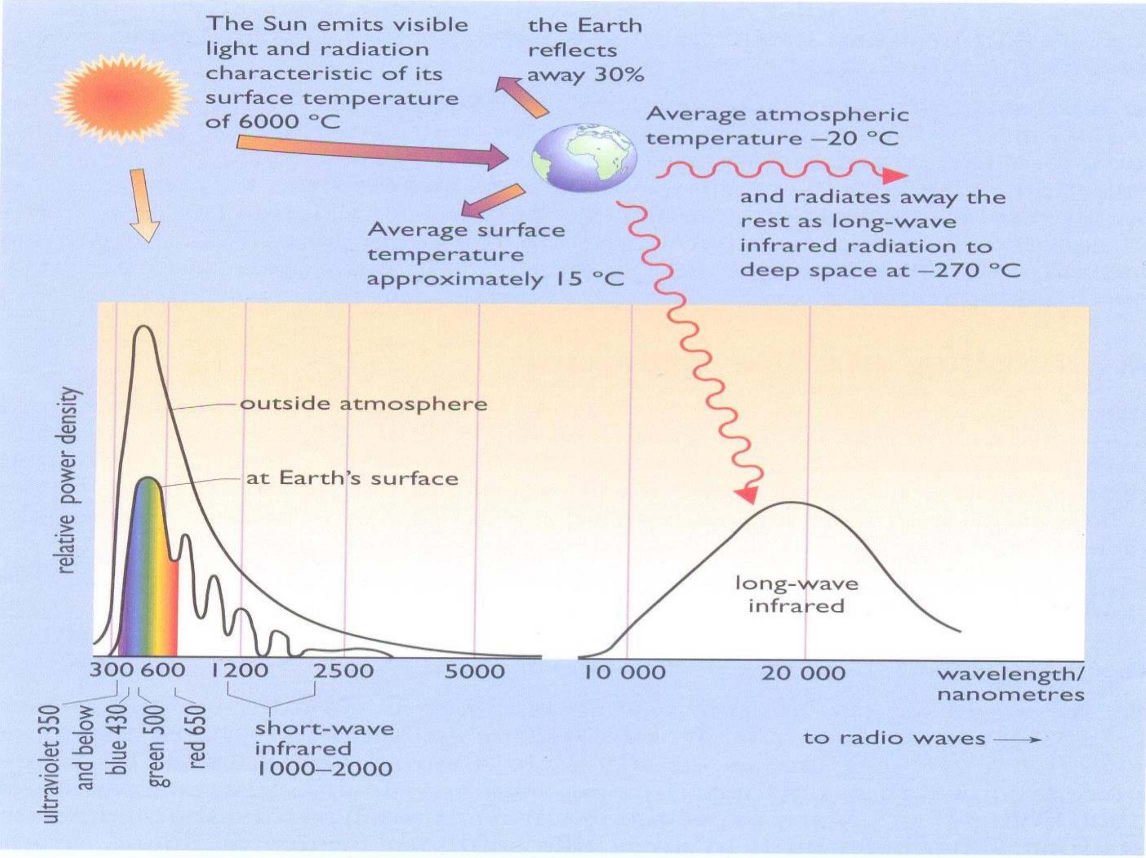
Incoming energy received from the sun, averaged over the year and over the surface area of the globe, is one fourth of solar constant *i.e.* 342 W/m^2.

77 W/m^2 are reflected back to space by clouds, aerosols and the atmosphere,

67 W/m^2 are absorbed by the atmosphere.

198 W/m^2, *i.e.* about 57% of the total, hits the earth's surface (on average).

Solar Radiation



Components of Solar Radiation

Beam Radiation/Direct Radiation

only beam radiation can be focused.

Diffused Radiation/Indirect Radiation/Scattered Radiation

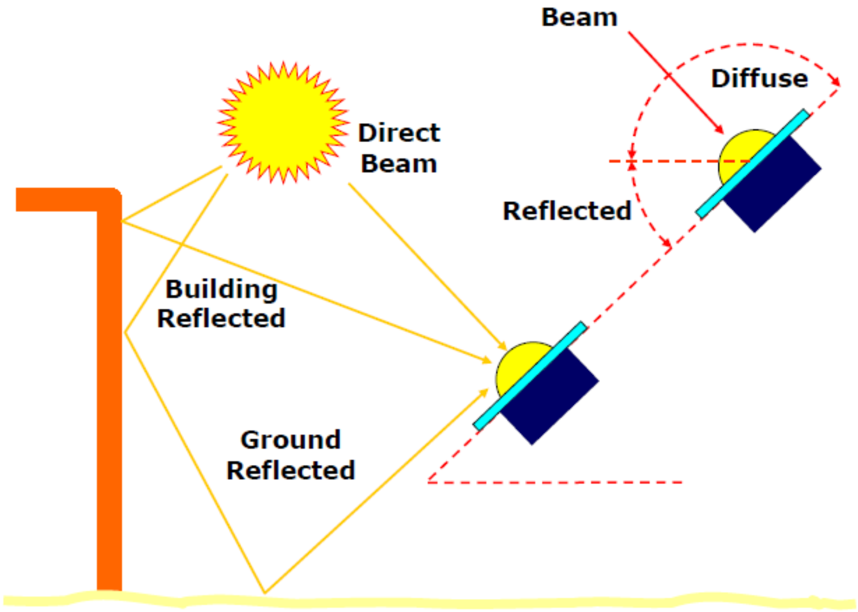
scattered due to combination of aerosols, clouds, dust etc.

For any solar device one may also account for a third component – the diffuse radiation reflected by ground surfaces.

Beam irradiance/Total Irraidance = Ranges from 0.9 -0

Components of Solar Radiation

Diffuse Radiation: The solar radiation received from the sun after its direction has been changed by scattering by the atmosphere.



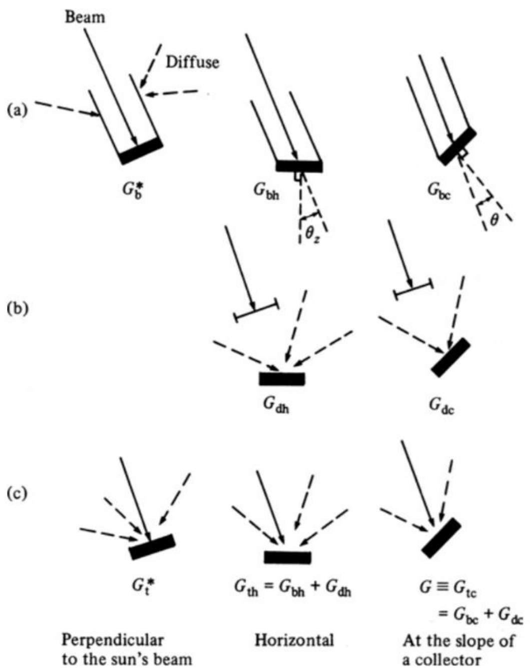
Components of Solar Radiation

$$G_{bc} = G_b^* \cos\theta$$

where θ is the angle between the beam and the normal to the collector surface

$$G_{bh} = G_b^* \cos\theta_z$$

θ_z is the (solar) zenith angle between the beam and the vertical



Irradiation & Irradiance

Irradiance is the rate at which radiant energy is incident on a surface per unit area of surface. It is given in W/m^2 and is represented by the symbol G.

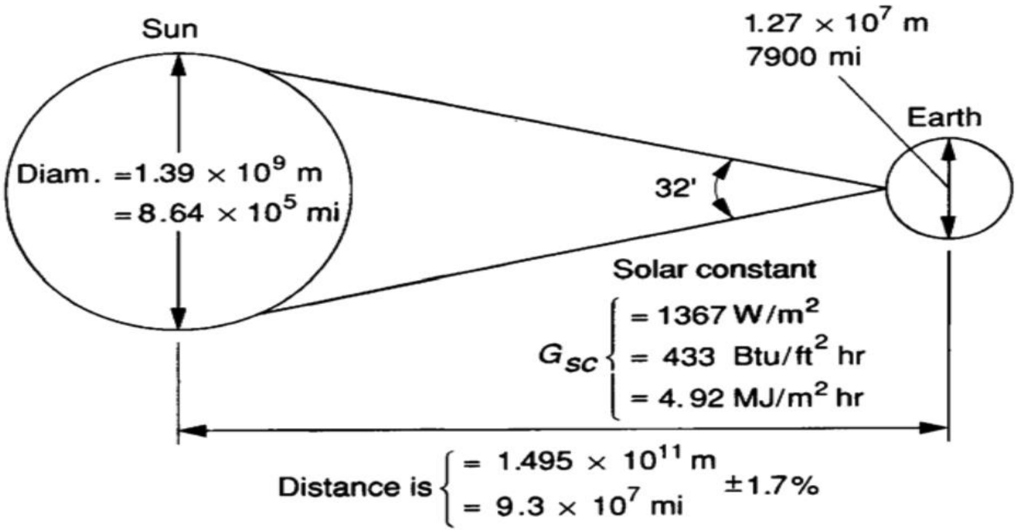
Irradiation is the incident energy per unit area on a surface - determined by integration of irradiance over a specified time, usually an hour or a day. It is given in J/m^2

Insolation is a term used for solar energy irradiation

Radiosity is the rate at which radiant energy leaves a surface, per unit area, by combined emission, reflection and transmission.

Relationship of Sun & Earth

The solar constant, G_{SC} is the energy from the sun, per unit time, received on a unit area of surface perpendicular to the direction of propagation of the radiation, at mean earth-sun distance, outside of the atmosphere.



Extra terrestrial solar radiation

The amount of extraterrestrial radiation reaching the earth is given by

$$I_o = 1367\left(\frac{R_{av}}{R}\right)^2 \quad \text{W/m}^2$$

R_{av} : the mean sun-earth distance
R: the actual sun-earth distance on the day of the year

$(R_{av} / R)^2 = 1.00011 + 0.034221 * \cos(b) + 0.001280 * \sin(b) + 0.000719 * \cos(2b) + 0.000077 * \sin(2b)$

b = 2π (d_n-1) / 365 radians and d_n is the day of the year

Extra terrestrial solar radiation

The area beneath this curve is the *solar constant G0* = 1366 ±2 W/m²*. *This is the radiant flux* density (RFD) incident on a plane directly facing the Sun and outside the Earth's atmosphere at a distance of 1.496 × 108 km from the Sun (i.e. at the Earth's mean distance from the Sun).

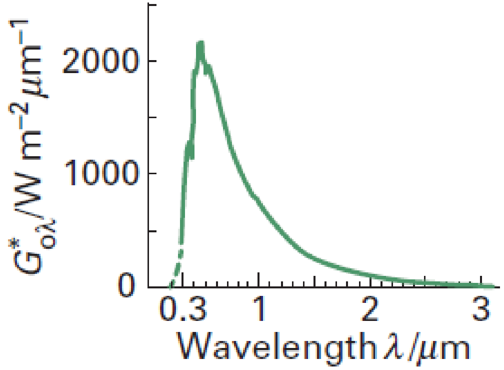
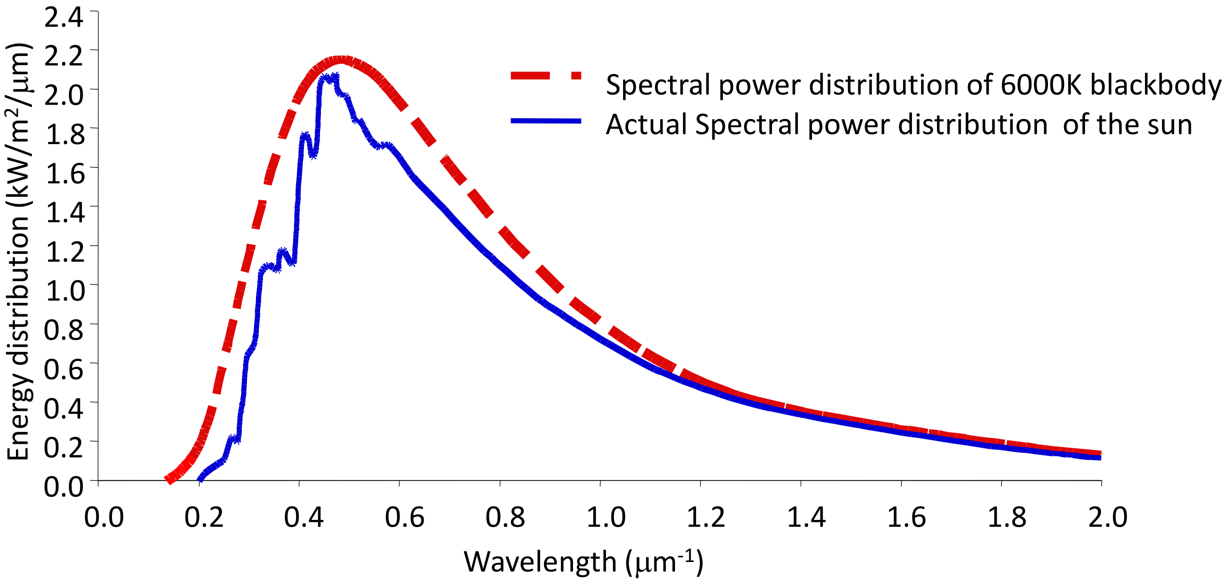


Fig. 2.1

Spectral distribution of extra-terrestrial solar irradiance, $G^*_{0\lambda}$. Area under curve equals 1366±2 W/m²

Extra terrestrial solar radiation



Extra terrestrial solar radiation

1. Ultraviolet region ($\lambda < 0.4\ \mu m$) ~5% of the irradiance
2. Visible region ($0.4\ \mu m < \lambda < 0.7\ \mu m$) ~43% of the irradiance
3. Near infrared) region ($\lambda > 0.7\ \mu m$) ~52% of the irradiance.

The proportions given above are as received at the Earth's surface with the Sun incident at about 45 degrees.

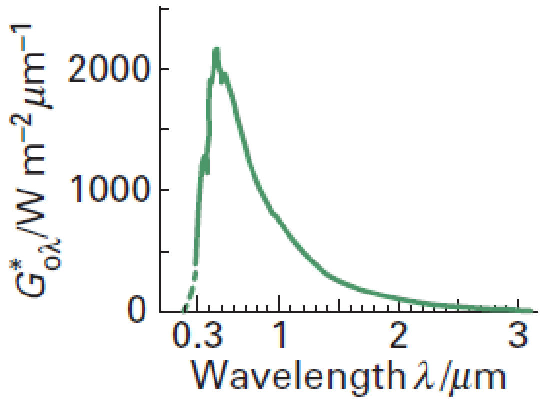


Fig. 2.1

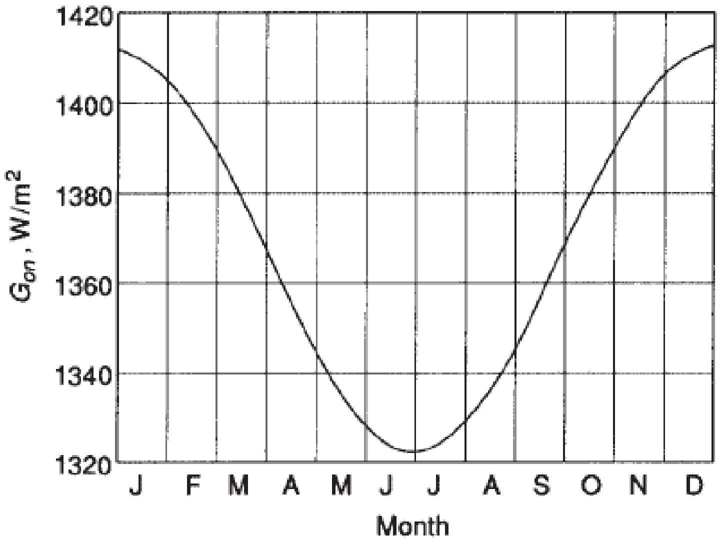
Spectral distribution of extra-terrestrial solar irradiance, $G^*_{0\lambda}$. Area under curve equals 1366±2 W/m²

Extra terrestrial solar radiation

Variation in the radiation emitted by the sun.
Variation of the earth-sun distance.

$$G_{on} = \begin{cases} G_{sc}\left(1 + 0.033\cos\dfrac{360n}{365}\right) \\ G_{sc}(1.000110 + 0.034221\cos B + 0.001280\sin B \\ \quad +0.000719\cos 2B + 0.000077\sin 2B) \end{cases}$$

$$B = (n-1)\frac{360}{365}$$



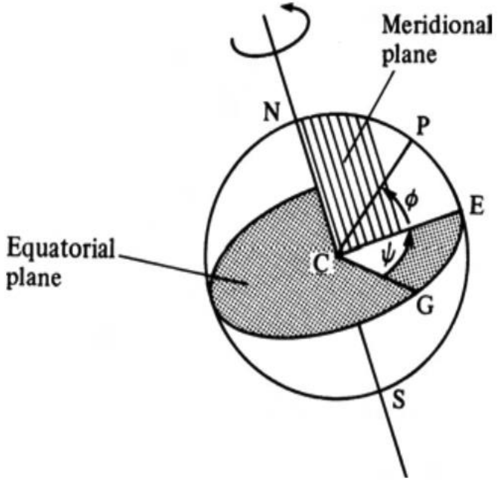
For engineering purposes, in view of the uncertainties and variability of atmospheric transmission, the energy emitted by the sun can be considered to be fixed.

Geometry of Earth and Sun

Latitude is defined positive for points north of the equator, negative south of the equator

Longitude is measured positive eastwards from Greenwich, England.

The vertical north– south plane through P is the local meridional plane.



Geometry of Earth and Sun

The point P on the Earth's surface is determined by its latitude ϕ and longitude; ϕ is positive for points north of the Equator, negative south of the Equator. By international agreement, Ψ is measured positive eastwards from Greenwich, England

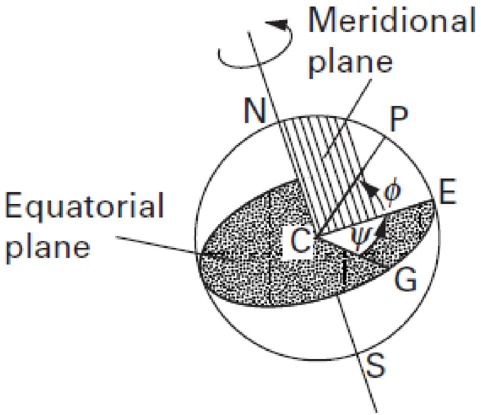


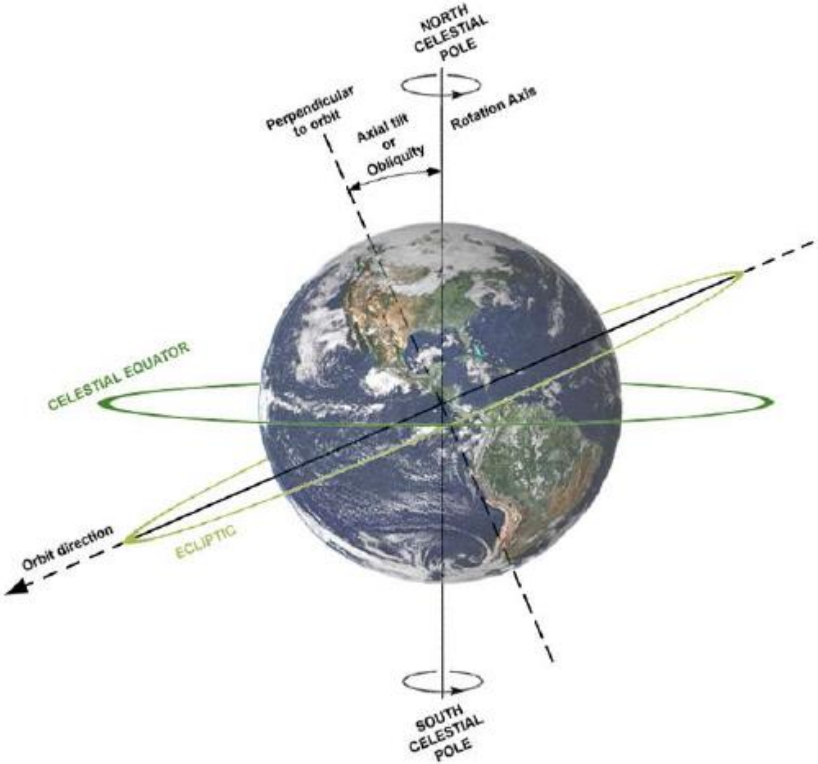
Fig. 2.4

Definition sketch for latitude ϕ and longitude ψ (see text for detail).

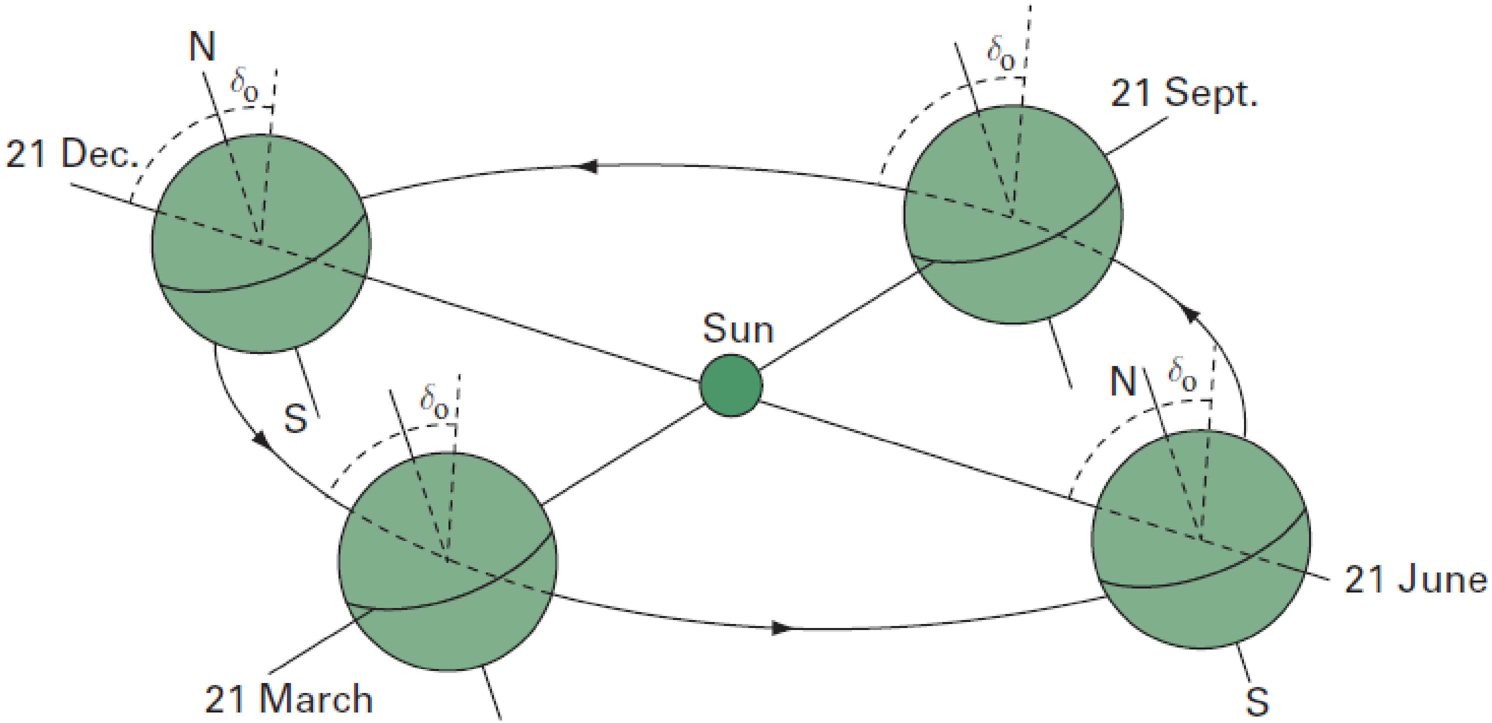
Geometry of Earth and Sun

(Latitude and Longitude)

Geometry of Earth and Sun



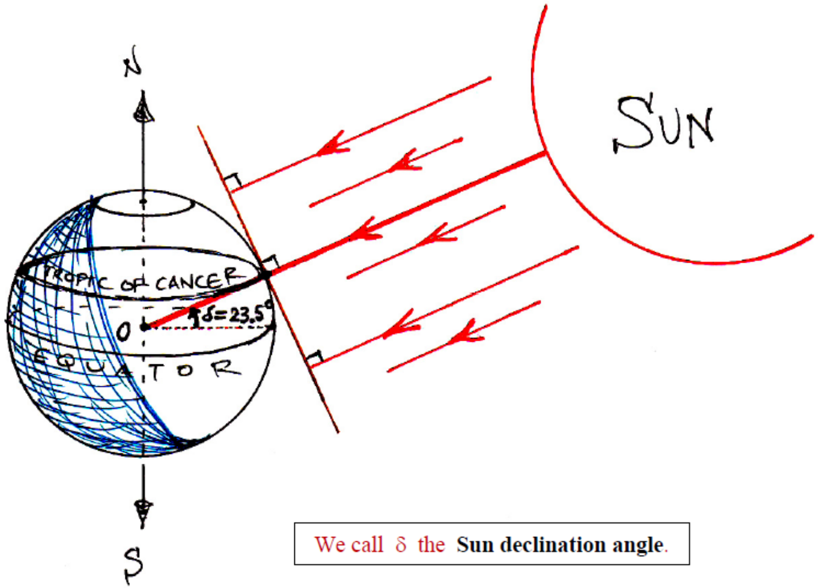
Geometry of Earth and Sun



Geometry of Earth and Sun (Declination angle)

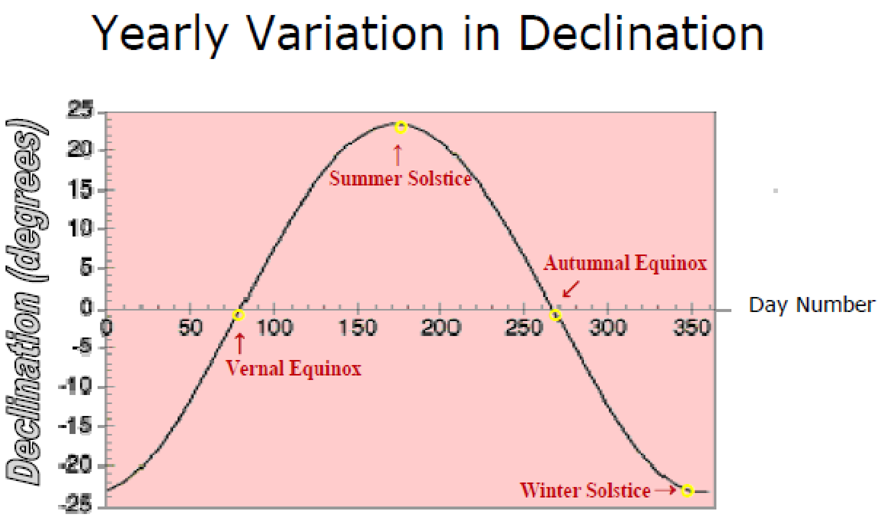
The Sun declination angle, is defined to be that angle made between a ray of the Sun, when extended to the center of the earth, O, and the equatorial plane.

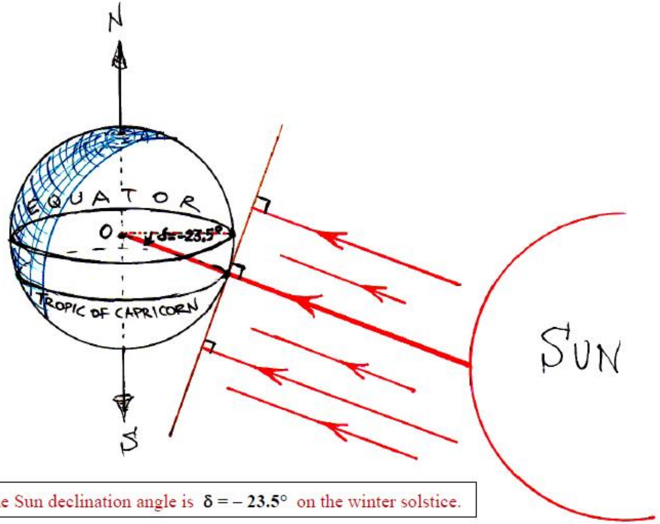
We take δ to be positively oriented whenever the Sun’s rays reach O by passing through the Northern hemisphere



We call δ the **Sun declination angle**.

Geometry of Earth and Sun (Declination angle)





The Sun declination angle is $\delta = -23.5°$ on the winter solstice.

$$\delta = \delta_0 \sin[360°(284 + n)/365]$$

where n is the day in the year ($n = 1$ on January 1).

Geometry of Earth and Sun (Declination angle)

- The Earth is above the plane of the Sun during its motion from the autumnal equinox to winter solstice to vernal equinox. Hence, $\delta < 0$ during the fall and winter.
- The Earth is below the plane of the sun as it moves from vernal equinox to summer solstice and back to autumnal equinox (i.e. during spring and summer). So $\delta > 0$ during these seasons.

Geometry of Earth and Sun(Solar hour angle)

- **Solar Time** based on the apparent angular motion of the sun across the sky with solar noon the time the sun crosses the meridian of the observer.
- Solar Noon is defined to be that time of day at which the Sun's rays are directed perpendicular to a given line of longitude. Thus, solar noon occurs at the same instant for all locations along any common line of longitude.
- Solar Noon will occur one hour earlier for every 15 degrees of longitude to the east of a given line and one hour later for every 15 degrees west. (This is because it takes the Earth 24 hours to rotate 360°.)

Geometry of Earth and Sun (Solar hour angle)

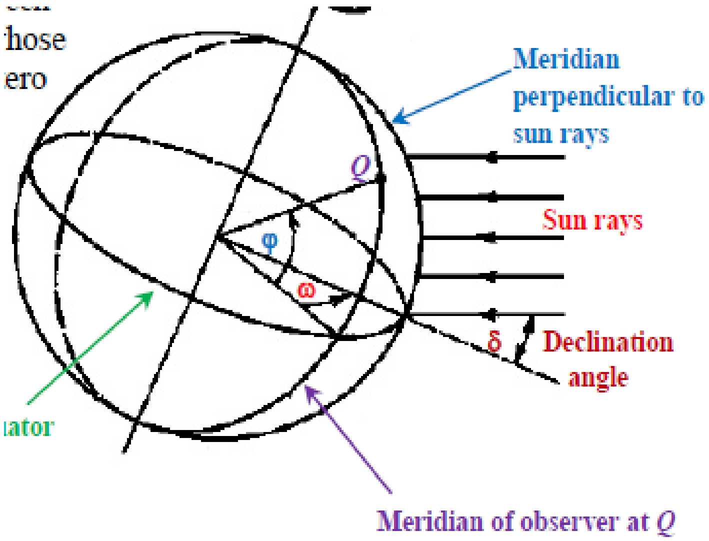
The hour angle ω at P is the angle through which the Earth has rotated since solar noon. Since the Earth rotates (360°/24h) = 15°/h, the hour angle is given by:

$$\omega = (15°/h^{-1})(t_{solar} - 12h)$$
$$= (15°/h^{-1})(t_{zone} - 12h) + \omega_{eq} + (\psi - \psi_{zone})$$

where t_{solar} and t_{zone} are respectively the local solar and civil times (measured in hours), Ψ_{zone} is the longitude where the Sun is overhead when t_{zone} is noon (i.e. where solar time and civil time coincide). ω is positive in the evening and negative in the morning.

Geometry of Earth and Sun (Hour Angle)

The hour angle, ω, is the angular distance between the meridian of the observer and the meridian whose plane contains the sun. Thus, the hour angle is zero at *local noon (when the sun reaches its highest* point in the sky). The hour angle increases by 15 degrees every hour.



Geometry of Earth and Sun (Hour Angle)

To convert standard time to solar time by applying two corrections. First, there is a constant correction for the difference in longitude between the observer's meridian (longitude) and the meridian on which the local standard time is based. The sun takes 4 min to transverse 1◦ of longitude. The second correction is from the equation of time, which takes into account the perturbations in the earth's rate of rotation which affect the time the sun crosses the observer's meridian. The difference in minutes between solar time and standard time is

$$\text{Solar time} - \text{standard time} = 4(L_{st} - L_{loc}) + E$$

$$E = 229.2(0.000075 + 0.001868 \cos B - 0.032077 \sin B - 0.014615 \cos 2B - 0.04089 \sin 2B)$$

$$B = (n - 1)\frac{360}{365}$$

Geometry of Earth and Sun (Hour Angle)

For Lahore (longitude 74.329) what will be the solar time corresponding to 11 AM on PST on 6th March.

Geometry of Earth and Sun

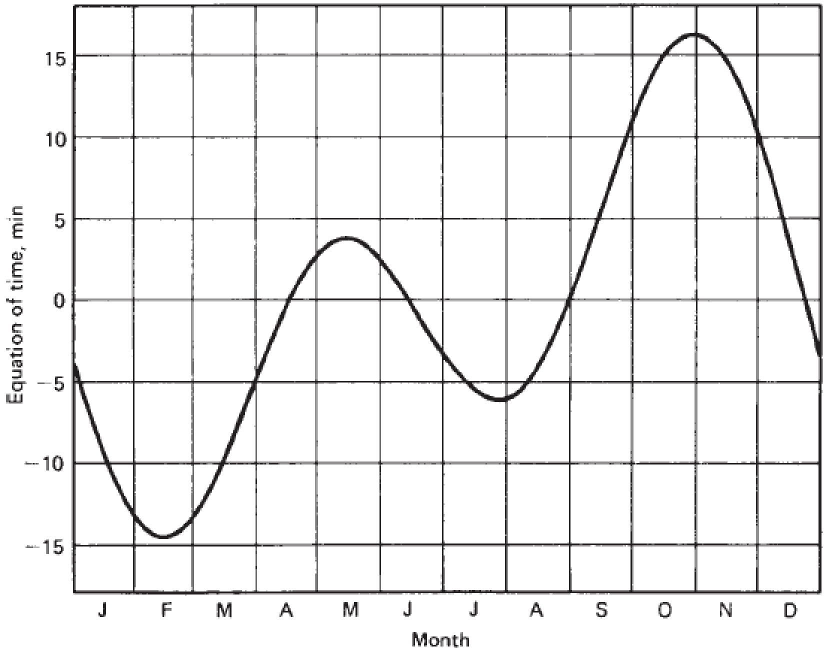


Figure 1.5.1 The equation of time E in minutes as a function of time of year.

Geometry of Earth and Sun

Collector, Slope, Azimuth and incidence angle)

Slope β: the angle between the plane surface in question and the horizontal.

Surface azimuth angle γ: projected on the horizontal plane, the angle between the normal to the surface and the local longitude meridian.

Angle of incidence θ: angle between solar beam and surface normal

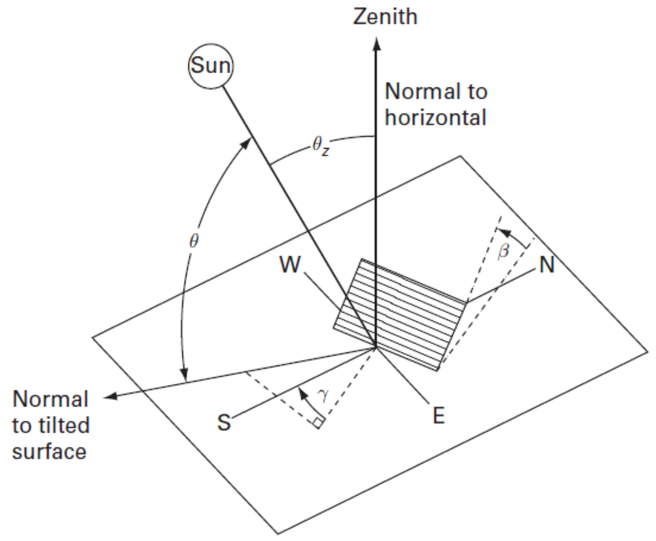


Fig. 2.9

Zenith angle θ_z, angle of incidence θ, slope β and azimuth angle γ for a tilted surface.

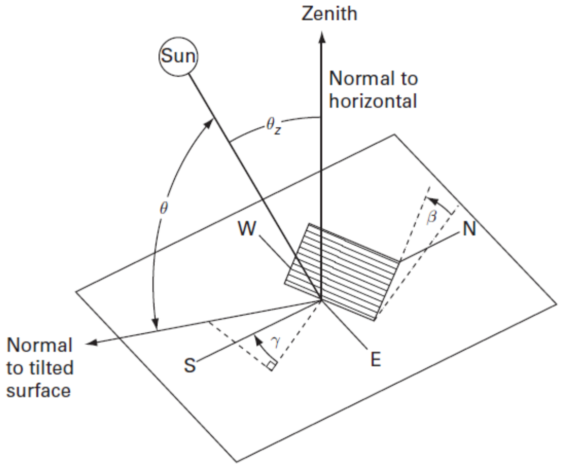
Note: for this easterly-facing surface $\gamma < 0$.

Source: After Duffie and Beckman (2006).

Geometry of Earth and Sun(Solar hour angle)

Beam, Zenith, altitude and azimuth angle

(Solar) zenith angle θz*:* angle between the solar beam and the vertical.
Solar altitude angle α_s: the complement to the (solar) zenith angle; angle of solar beam to the horizontal.
Sun (solar) azimuth angle γs: projected on the horizontal plane, the angle between the solar beam and the longitude meridian.



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Geometry of Earth and Sun

$$\cos\theta = (A-B)\sin\delta + [C\sin\omega + (D+E)\cos\omega]\cos\delta$$

where

$A = \sin\phi\cos\beta$ $\quad$ $B = \cos\phi\sin\beta\cos\gamma$

$C = \sin\beta\sin\gamma$ $\quad$ $D = \cos\phi\cos\beta$

$E = \sin\phi\sin\beta\cos\gamma$

and

$$\cos\theta = \cos\theta_z\cos\beta + \sin\theta_z\sin\beta\cos(\gamma_s - \gamma)$$

$$\cos\theta = \cos\theta_z\cos\beta + \sin\theta_z\sin\beta\cos(\gamma_s - \gamma)$$

$$\cos\theta = \cos\omega\cos\delta$$

Geometry of Earth and Sun

Noon solar time occurs once every 24 h when the meridional plane CEP includes the Sun, as for all points having that longitude.

Civil time is defined so that large parts of a country, covering up to 15°of longitude, share the same official time zone.

Geometry of Earth and Sun

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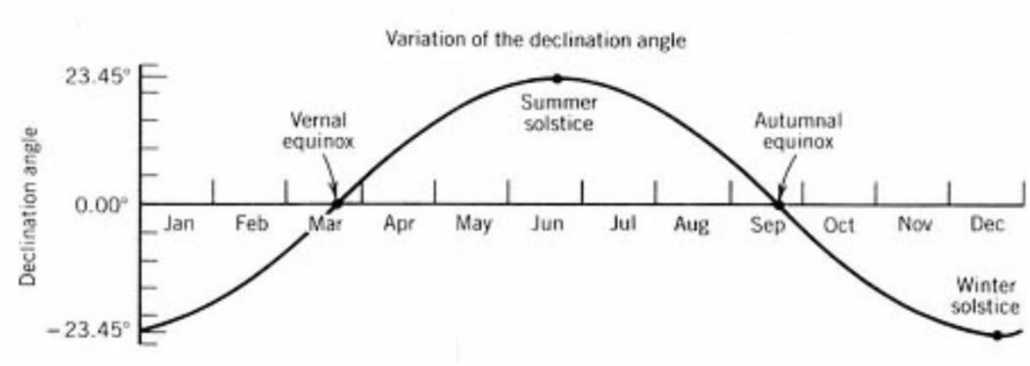
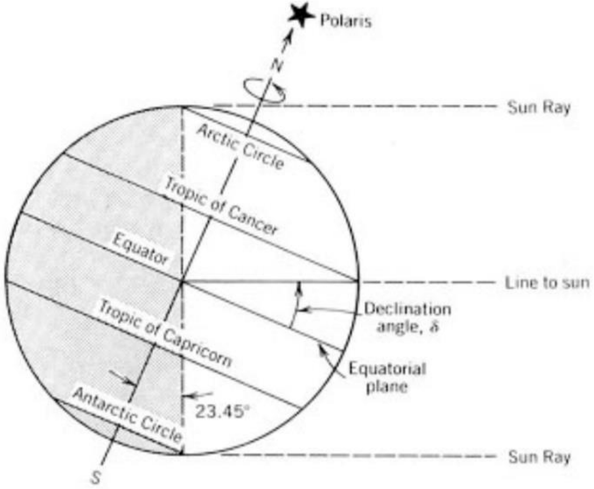
$$\omega = (15^\circ\,\mathrm{h}^{-1})(t_{\mathrm{solar}} - 12\,\mathrm{h})$$
$$= (15^\circ\,\mathrm{h}^{-1})(t_{\mathrm{zone}} - 12\,\mathrm{h}) + \omega_{\mathrm{eq}} + (\psi - \psi_{\mathrm{zone}})$$

Civil time is defined so that large parts of a country, covering up to 15°of longitude, share the same official time zone.

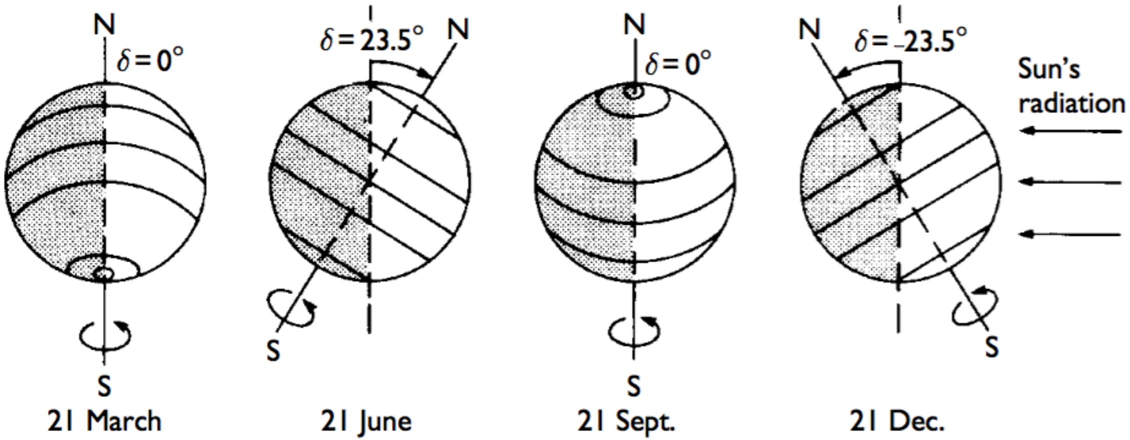
$$\delta = \delta_0 \sin\left[\frac{360^\circ(284+n)}{365}\right]$$

Geometry of Earth and Sun





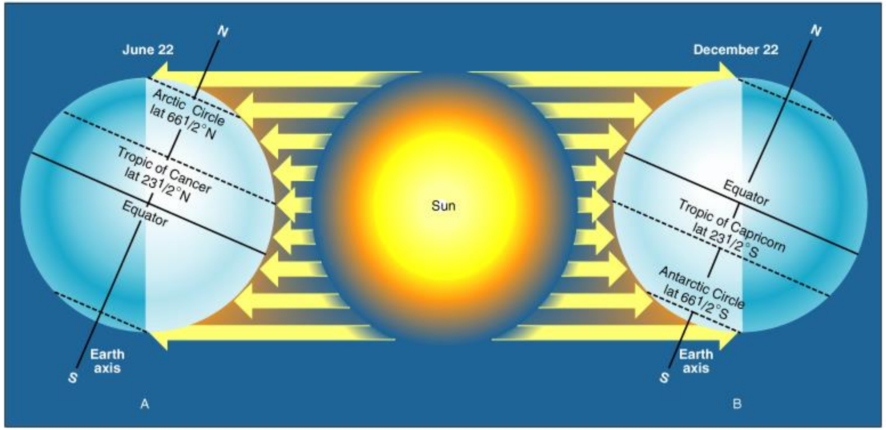
Geometry of Earth and Sun



The Earth, as seen from a point further along its orbit. Circles of latitude 0º,±23.5º,±66.5º are shown. Note how the declination δ varies through the year, equaling extremes at the two solstices and zero when the midday Sun is overhead at the equator for the two equinoxes (equal day and night on the equator).

Geometry of Earth and Sun

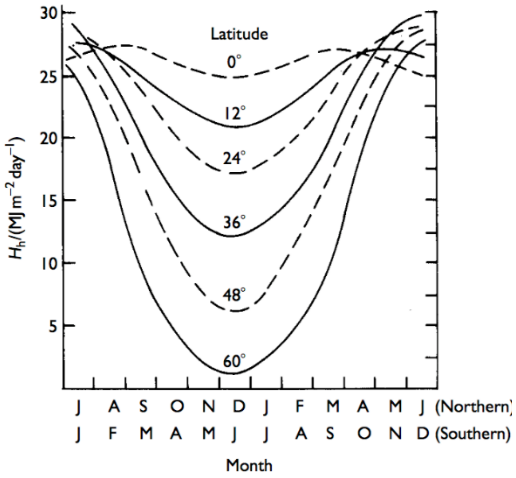
The seasons occur because the tilt of the Earth's axis keeps a constant orientation as the Earth revolves around the Sun. A. Summer in northern hemisphere. B. Winter in southern hemisphere



Geometry of Earth and Sun

Daily insolation H is the total energy per unit area received in one day from the sun:

$$H = \int_{t=0\,\mathrm{h}}^{t=24\,\mathrm{h}} G\,\mathrm{d}t$$

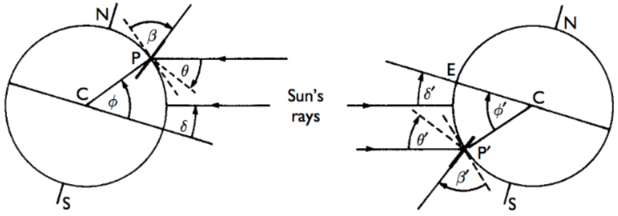


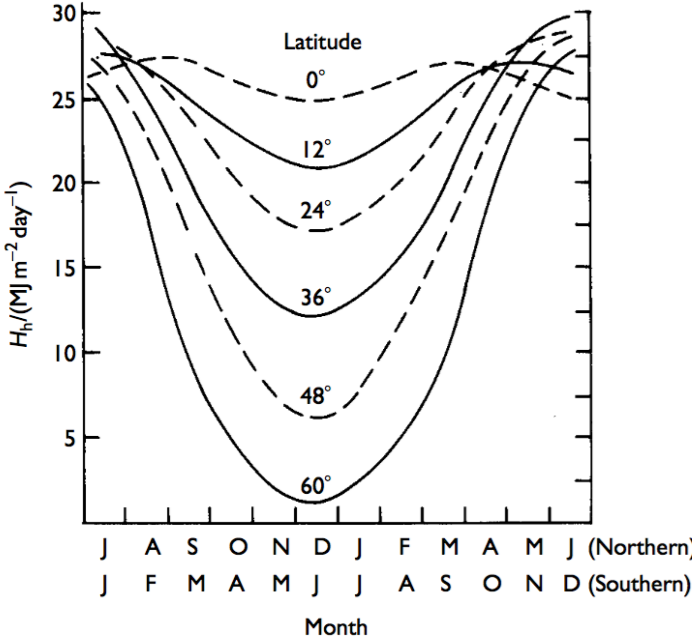
Three key reasons for variation are:

- Variation in length of the day

Geometry of Earth and Sun

- Orientation of the receiving surface





- Variation in atmospheric absorption

Home Work

Chapter 04: Renewable-Energy-Resources-By-John-Twidell-Tony-Weir

Problem Sheet 02: Solar Energy

Thank You